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Ceramic HEPA Filter Program

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EFCOG SAWG Safety Analysis Workshop, NSR&D Interest
Group
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Ceramic HEPA Filter Program

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May 2012

Mark Mitchell et al, LLNL Ceramic
HEPA Filter Program Manager



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Status Report of LLNL Ceramic HEPA Filter Program (Outline)

- Potential benefits of ceramic filters in nuclear facilities
 - Short Term, Intermediate, Long Term Benefits
 - Technical Benefits of Ceramic Filter Technology
 - Potential DOE Cost Savings
 - DOE Complex Needs Analysis
- History
 - International R&D
 - U.S. R&D
- Results
 - DOE Filter Test Facility Test Results
 - ICET Testing – forthcoming
- Current Technical Developments & Pathforward
 - Testing at LLNL, DOE Filter Test Facility, and ICET
 - Filter, component, and material testing at CalPoly's High Temperature Test Unit (HTTU)
 - Novel materials R&D
- Conclusion
- Thanks

Potential Benefits of Ceramic Filters in Nuclear Facilities

- Short term benefit for DOE, NRC, and industry
 - CalPoly HTTU provides unique testing capability to answer questions for DOE
 - High temperature testing of materials, components, filter
 - Several DNFSB correspondences and presentations by DNFSB members have highlighted the need for HEPA filter R&D
 - DNFSB Recommendation 2009-2 highlighted a nuclear facility response to an evaluation basis earthquake followed by a fire (aka shake-n-bake)
 - CalPoly has capability for a shake-n-bake test
- Intermediate term benefit for DOE and industry
 - Filtration for specialty applications, e.g., explosive applications at Nevada
 - Spin-off technologies applicable to other commercial industries
- Long term benefit for DOE, NRC, and industry
 - Across industry, strong desire for better performance filter
 - Engineering solution to safety problem will improve facility safety and decrease dependence on associated support systems
 - Large potential life-cycle cost savings
 - Facilitates development and deployment of LLNL process innovations to allow continuous ventilation system operation during a fire

Benefits of Ceramic Filter Technology

- Overcome problems with existing technologies
 - Disadvantages of existing HEPA filters result in significant design, operational, and compliance costs for associated fire protection and support systems
 - Easily damaged by fires, moisture, chemicals, high pressures and high temperatures
 - Poor performance in a fire
 - Wet traditional HEPA filters are substantially weakened
 - Recent events with DNFSB
 - DNFSB Recommendation 2009-2 highlights this issue for a nuclear facility response to an evaluation basis earthquake followed by a fire (LANL PF-4)
 - DNFSB comments on a new facility under construction (CMRR) highlighted significance of HEPA filter issues and escalated costs (note current status of CMRR)
 - DNFSB comments at additional DOE sites continue in 2012
 - HEPA filters - key credited element in defense-in-depth safety strategy of DOE facilities
 - Focus on engineering safety solutions rather than primarily additional DSA analysis
 - Increase safety and performance, while significantly lowering cost (save DOE millions annually)
 - Reduce or eliminate safety basis costs associated with safety class and safety significant systems in nuclear facilities, e.g., fire suppression, fire detection and alarm, and internal building structure
 - Open processing avenues closed by current technology & regulations, e.g., provide protection for acid-based operations to replace Teflon™ pre-filters (DNFSB criticism)

Technical Benefits of Ceramic Filters for Nuclear Facility Ventilation

- **Superior performance, wider operational range**

- High temperature & moisture resistant
- Increase safety of operations
- Fills a gap in filtration technologies
- Optimize overall system performance

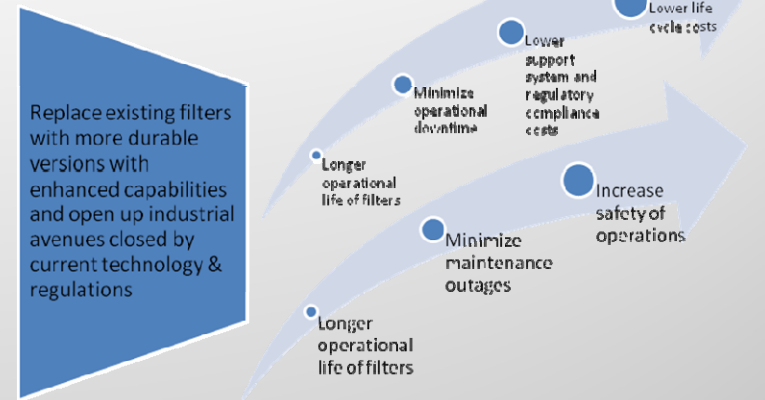
- **Superior performance during Fire**

- Ceramic HEPA filters are nonflammable
 - Superior performance during facility fire
- Ceramic HEPA filters can perform their safety function if wetted and exposed to greater pressures
 - Facilities often designed with HEPA-filtered exhaust systems and water-based fire suppression systems
 - Traditional HEPA filters subjected to wetting to protect them from high temperature are substantially weakened

- **Ceramic filter technology would allow additional life cycle cost savings**

- Ceramic filter could be cleaned (e.g., in place) and reused, thereby reducing secondary waste
- Minimize associated costs and risks of contamination posed by “hot breaks”
- Designed to minimize retrofit problems and costs while meeting several key HEPA filter requirements

Ceramic HEPA Filter Advantages

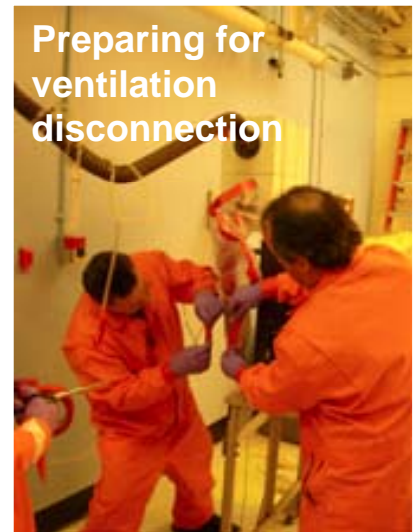


Current HEPA Filter Technology

Safety & Maintenance Costs



Preparing for
ventilation
disconnection



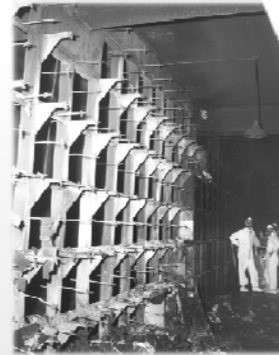
Potential to Save Millions of Dollars Annually Across DOE Complex

- **Lower life-cycle costs**
 - Estimates based on data from ten year's of testing throughput at DOE Complex Filter Testing Facility (ATI) and a sampling of DOE nuclear facilities
 - **Lower waste disposal costs**
 - Significantly reduce radioactive waste disposal costs, while also decreasing design and operational costs associated with related safety significant systems in nuclear facilities
 - Save DOE \$11M to > \$36M annually
 - **Lower operational costs**
 - Reduce or eliminate safety basis costs associated with safety class and safety significant systems in nuclear facilities, e.g., fire suppression, fire detection and alarm, and internal building structure
 - Save DOE an additional \$1M to \$10M annually

Additional Opportunities to Benefit DOE Complex

- Consider ceramic filter technology for
 - Use in robust long-term storage of plutonium and other radioactive materials
 - Application in radial filter designs used by DOE-EM and the United Kingdom
 - Replacement of existing filters for inline process filters
 - Applications in chemically hostile environments (e.g., strongly acidic, humid, corrosive)
- Additional filter applications as agreed upon between partnering sites, LLNL, and other potential partnering organizations
 - Potential benefits to DOD, DHS, CDC, NASA, commercial partners, as well as nonproliferation partners in coordination with DOE/State Department
 - Other benefits to DOE Energy projects, e.g., coal, clean coal, commercial nuclear power
 - Ceramic filters offer high temperature performance (e.g., clean coal, solar)

Bottom Line



1957 & 1969 Rocky Flats Fires

- DOE Complex Needs Analysis
 - 100% of knowledgeable nuclear air cleaning professionals believe HEPA filter media strength is very, or extremely, important
 - 92% of knowledgeable nuclear air cleaning professionals believe it is important to develop alternatives to current glass-fiber filters



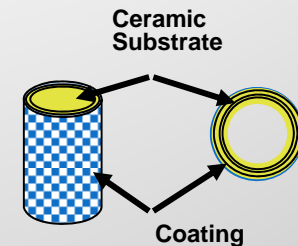
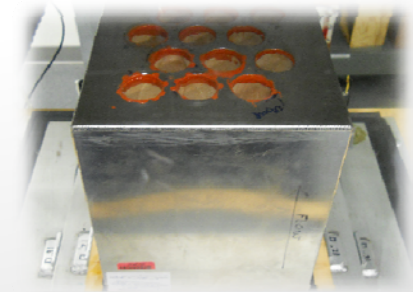
1980 fire, note performance of high temperature HEPA filters

History of Ceramic HEPA Filter Program

- LLNL has conducted research into more advanced HEPA filters for more than 30 years, e.g.,
 - Metal HEPA filters, Dr. Werner Bergman et al
- International R&D
 - Mark Mitchell & Dr. Werner Bergman initiated the ceramic HEPA filter research, including work by Russian national institutes
 - Bochvar, Bakor, and Radium Khlopin Institute
 - Resulted in ceramic HEPA filter proof-of-concept
- Current U.S. R&D (NSR&D)
 - Goal: Develop a fire resistant filter with better performance (e.g., heat, flame, moisture, corrosion, loading)

Current Program Status

- Completed international R&D tested a wide variety of ceramic substrates, coatings, and technologies to apply coatings
 - Downselected two filter technologies
 - LLNL testing Russian filter prototypes
 - Mini-assembly (8.5"x8.5"x11.5")
 - Full-scale assembly (2'x2'x11.5")
- Ongoing University Collaboration (CalPoly)
 - Enhanced testing capability - High Temperature Test Unit (HTTU)
 - HTTU provides an unique capability to test binders, sealants, and frames
 - See separate student presentation
 - Tooling capability to replace individual tubes in support of R&D and manufacturing
- LLNL R&D
 - Invented new sealants to be tested at CalPoly (HTTU)
 - Invented new filtration coatings
 - Commercial procurements of ceramic substrates
 - Innovative new coatings lab at LLNL
 - Novel filter coating apparatus designed, fabricated, installed, and in testing



Full-Scale Assembly

International R&D - Nonproliferation

- Potential for a successful, self-sustaining enterprise for the long term employment of WMD scientists, engineers, and technicians
 - Russians employed in their respective areas of expertise, utilizing existing facilities, performing work that appeals to their interests and skills
- Russian R&D nuclear and ceramics capabilities
 - Bochvar
 - Leading Russian institute conducting research on fuel cycle technologies & fissile materials processing
 - Founded in 1945 to solve materials science and technology problems related to the production of nuclear weapons
 - Capabilities in ceramic technology, emphasis on applied technology at large scales
 - Radium Khlopin
 - Developed reprocessing technologies for fissile materials production
 - Conducts research and development for the nuclear industry, analytical laboratory services, environmental investigations of nuclear tests, designs accident response procedures, produces isotopes
- Goal:
 - Develop ceramic HEPA filter technology and establish working relationship between U. S. industrial partner and Russian nuclear laboratories
 - Long term employment of Russian WMD scientists, engineers, and technicians to fabricate ceramic HEPA filters for U. S., Russian, and foreign markets, and conduct ongoing R&D services

Russian Research Review



Russian R&D Explored and Down-selected Ceramics and Designs for Membranes and Substrates



Filter Element with Aluminum-Oxide Membrane Made by Gas-Plasma Spraying Method



Fiber-Structured Filtering Element Samples



Various ceramic samples

Research included:

- Variety of Alumina Electrocorundums
- Disthene-Sillimanite
- SiC (numerous approaches) substrate
- Aluminum oxide substrate
- Preparation techniques such as slurry molding, casting, plasma deposition, proprietary vacuum deposition

Russian filter proof-of-concept Testing at ATI



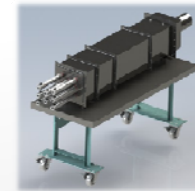
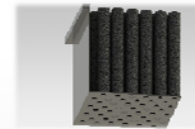
- Successful proof-of-concept
- Independent verification of HEPA filtration (>99.97% filtration efficiency) at
 - 30 cfm (dP 2.8")
 - 71 cfm (dP 6.1")
- Unsatisfactory dP
 - R&D of novel coatings at LLNL to reach final goal

Russian filter proof of concept- Testing at ICET forthcoming



- Utilize existing test stand used to qualify metal HEPA filters for AG-1 to also qualify ceramic HEPA filters

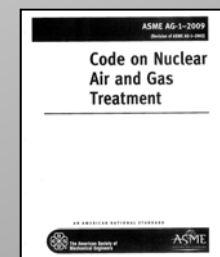
Current Technical Developments



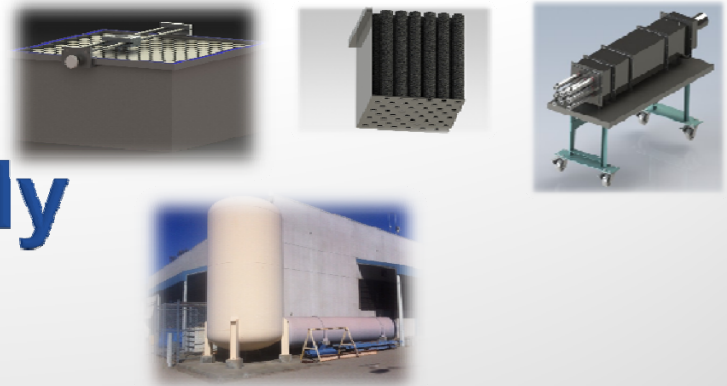
- Research a ceramic HEPA filter technology meeting specifications of existing nuclear grade HEPA systems
 - Three Main Projects
 - Ceramic HEPA Filter Testing at LLNL, DOE Filter Test Facility (ATI), and ICET
 - University Collaboration (CalPoly) student projects to develop improved testing capabilities (HTTU provides an unique capability to test binders, sealants, and frames)
 - Novel coatings research at LLNL to reduce dP and maintain filtration efficiency
 - Revise Bureaucracy Accordingly
 - Write new ASME AG-1 code section to enable NNSA, DOE-EM, others to buy better, stronger, safer, HEPA filters
 - Revise DOE-STD-3020 (normally AG-1 is a prerequisite but discussions with HS-33 indicate flexibility)
 - Intellectual Property and CRADA
 - Portfolio of over a dozen inventions and patents

Current Technical Developments - Testing

- Prototype Ceramic HEPA Testing at LLNL, ATI, and ICET
 - ASME 510 leak test at LLNL industrial hygiene laboratory
 - Scanning individual components and assembled HEPA filter
 - Certification testing at ATI complete
 - Future filters will likewise be sent to ATI for testing
 - Next step: ICET qualification testing of Russian proof-of-concept filters
 - Future filters will likewise be to ICET
 - Pave the way for revised regulations (i.e., new ASME AG-1 Section for Ceramic Filters and DOE-STD-3020)



Current Technical Developments - CalPoly

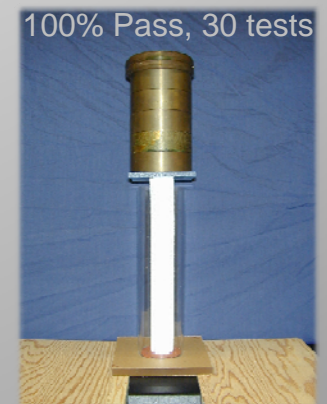


- Tooling Project – Complete
- High Temperature Testing Unit (HTTU) to study HEPA filter behavior as effected by fire conditions
 - HTTU provides an unique capability to test binders, sealants, and frames
 - Primarily targeted for ceramic filters, but can support studies of non-ceramic filters if desired
 - Status
 - Design HTTU and Control System – Complete
 - Fabrication, test and demonstrate HTTU – In progress
 - Install and test controls & instrumentation for HTTU – In progress
 - Conduct experiments on various HEPA filter materials and designs
 - Better sealants, binders, and other components (e.g., frames)
 - Question: Any interest in integral welded frame with a flat sealing surface instead of bolted frame?
 - Question: Any interest in shake-n-bake test capability?

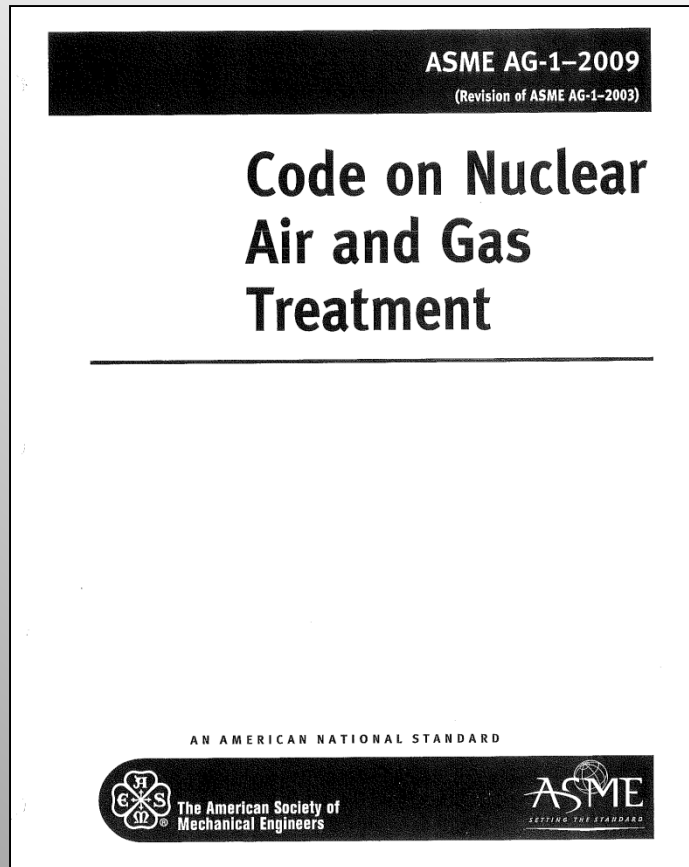
Current Technical Developments – Novel Materials



- Novel material coatings research
 - Reduce the pressure drop while maintaining filtration efficiency
 - Develop and test of improved filtration materials for ceramic filters using LLNL developed innovations
 - Research contract fabrication opportunities - Complete
 - Procured R&D quantity of substrate elements (tubes)
 - Proof test (compressive strength) tubes - Complete
 - Measure dP of tubes at flow rates required by 3020
 - Complete for substrates
 - Developed deposition system for coating tubes
 - Testing - In progress



Create a new ASME AG-1 Section



- Necessary to enable NNSA, DOE-EM, others to buy better, stronger, safer, HEPA filters
 - NNSA contractor wanted to buy metal filters in 90's, but could not because code section not completed

Section FC	HEPA Filters
Section FD	Type II Adsorber Cells
Section FE	Type III Adsorbers
Section FF	Adsorbent Media
Section FG	Mounting Frames, CONAGT Air-Cleaning Equipment, Nuclear S Equipment
Section FH	Other Adsorbers
Section FI	Metal Media Filters (In the Course of Preparation)
Section FJ	Low Efficiency Filters (In the Course of Preparation)
Section FK	Special Round and Duct-Connected HEPA Filters
Section FL	Sand Filters (In the Course of Preparation)
Section FM	High Strength HEPA Filters (In the Course of Preparation)
Section IA	Instrumentation and Controls

FM Section

FI Section

Potential Applications: New and Existing Industry Markets

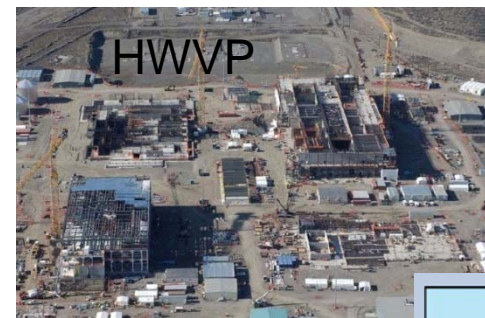
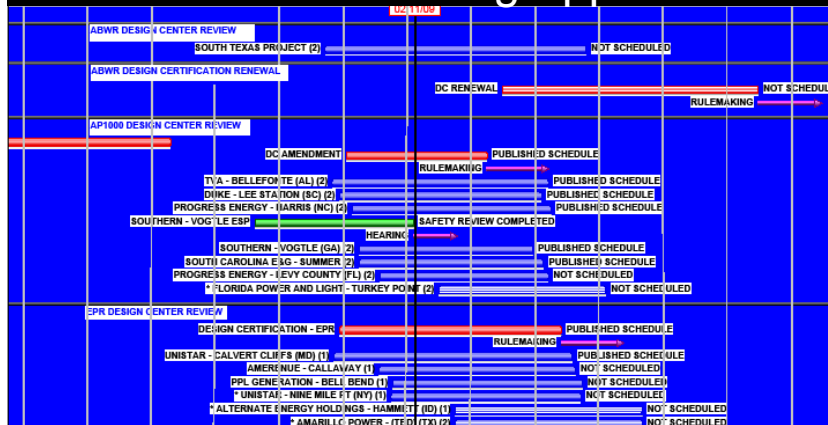
Commercial Applications

- Biotech/Biopharmaceutical Manufacturing
- Pharmaceutical Manufacturing
- Clean Coal Power Generation
- Hazardous Chemicals Processing
- Mining
- Metals Processing
- Wastewater Treatment
- Agriculture
- Semiconductor Fabrication

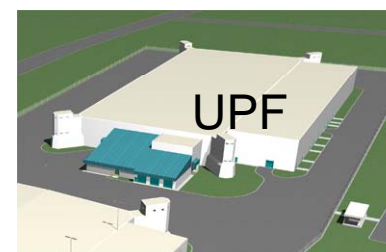
DOE/DOD/NRC Applications

- Aerospace Manufacturing
- Defense Industries
- Petroleum Processing
- Nuclear Power Generation
- Non-reactor Nuclear Facilities such as those under construction at Hanford, Y-12, and Savannah River

New Reactor Licensing Applications



AP-1000



MOX Fuel Fabrication Facility

Conclusions

- Research has short, intermediate, and long term benefits to DOE Complex, NRC, and industry
- Completed Russian R&D and successful proof-of-concept
- Ceramic HEPA Filter Program is developing unique capabilities to answer complex questions
- Path forward
 - Testing of binders, sealants, and frames
 - Research of novel material coatings to reduce dP and maintain filtration efficiency
 - Portfolio of over 12 inventions with provisional patents already filed
- We will continue to pursue DOE-HQ (NSR&D) funding for this program
- We welcome suggestions for future research ideas to best fit your needs

Authors

- Dr. Werner Bergman, Aerosol Science
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- Ron Beaulieu, NSTec Safety Basis Program Leader, (formerly LLNL)
- Paris Althouse, LLNL, GIPP Program Leader
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